

EVENT PIPELINE AND SUMMING METHOD AND  
APPARATUS FOR EVENT BASED TEST SYSTEM

5 This application claims the benefit of U.S. Provisional Application No. 60/396,040 filed July 13, 2002.

Field of the Invention

This invention relates to a semiconductor test system  
10 for testing semiconductor devices, and more particularly, to an event pipeline and summing method and apparatus for use in an event based semiconductor test system for generating test events of various types and timings at high speed to evaluate semiconductor devices under test.

15

Background of the Invention

In testing semiconductor devices such as ICs and LSIs by a semiconductor test system, such as an IC tester, a semiconductor IC device to be tested is provided with test  
20 signals produced by an IC tester at its appropriate pins at predetermined test timings and waveforms. The IC tester receives output signals from the IC device under test generated in response to the test signals. The output signals are strobed at predetermined timings and results are  
25 compared with expected data to determine whether the IC device functions correctly.

The assignee of this invention has developed an event based test system wherein the desired test signals and strobe signals are produced by event data from an event memory  
30 directly on a per pin basis. In an event based test system, test data is described in terms of event and its timing where events are any changes of the logic state in the signals used for testing a semiconductor device under test. For example, such changes are rising and falling edges of test signals

(drive events) or occurrences of strobe signal (strobe events or sample events). Typically, a timing of each event is defined either as a time length from the most recent event (immediately prior to the current event) or the absolute time 5 of an event.

The basic design of the event tester is disclosed in U.S. Patent Nos. 6,532,561 and 6,360,341, which is briefly described here. An example of basic structure in the event based test system is shown in a block diagram of Figure 1. 10 In the example of Figure 1, the event based test system includes a host computer 12 and a bus interface 13 both are connected to a system bus 14, an internal bus 15, an address control logic 18, a failure memory 17, an event memory 30 consisting of an event count memory (event count RAM) 20 and 15 an event vernier memory (event vernier RAM) 21, an event summing and scaling logic 22, an event generator unit 24, and a pin electronics 26. The event based test system evaluates a semiconductor device under test (DUT) 28 connected to the pin electronics 26. 20 An example of the host computer 12 is a work station having a UNIX, Window, or other operating system therein. The host computer 12 also provides a user interface to enable a user to instruct the start and stop operation of the test, to load a test program and other test conditions, or to 25 perform test result analysis in the host computer. The host computer 12 interfaces with a hardware test system through the system bus 14 and the bus interface 13.

The internal bus 15 is a bus in the hardware test system for interfacing the functional blocks such as the address 30 control logic (address controller) 18, failure memory 17, event summing and scaling logic 22, and event generator 24. An example of the address control logic 18 is a tester processor which is exclusive to the hardware test system. The tester processor (address control logic) 18 provides 35 instructions to other functional blocks in the test system

based on the test program and conditions from the host computer 12 as well as to generate address data for event memory 30 and failure memory 17. The failure memory 17 stores test results, such as failure information of the DUT 5 28. The information stored in the failure memory logic 17 is used in the failure analysis stage of the DUT.

In an actual test system, a plurality of sets of event count memory and event vernier memory will be provided, each set of which typically corresponds to a test pin of the test 10 system. The event count and vernier memories 20 and 21 store the timing data for each event of the test signals and strobes. The event count memory (RAM) 20 stores the timing data which is an integer multiple of the reference clock (event count data), and the event vernier memory (RAM) 21 15 stores timing data which is a fraction of the reference clock (event vernier data).

The event summing and scaling logic 22 is to produce a signal showing overall timing of each event based on the timing data from the event count memory 20 and the event 20 vernier memory 21. Basically, such overall timing signal (event enable) is produced by summing the event count data (integer multiple data) and the event vernier data (the fractional data). During the process of summing the timing data, a carry over operation of the fractional data (offset 25 to the integer data) is also conducted in the timing count and offset logic 22. Further during the process of producing the overall timing signal, timing data may be modified by a scaling factor so that the overall timing can be modified accordingly.

30 The event generator 24 is to actually generate the events based on the overall timing signal and the vernier sum data from the event summing and scaling logic 22. Typically, an event is generated by delaying the overall timing signal by the value shown in the vernier sum data. The events 35 (drive events and/or strobe events) thus generated are

provided to the DUT 28 through the pin electronics 26. Basically, the pin electronics 26 is formed of a large number of components, each of which includes a driver and a comparator as well as switches to establish input and output 5 relationships with respect to the DUT 28.

For producing high resolution timings, as noted above, the time length (delay value) between the events is defined by a combination of an integral part of the reference clock (event count data) and a fractional part of the reference 10 clock (event vernier data). A timing relationship between the event count and the event vernier is shown in a timing chart of Figures 2A-2D. In this example, a reference clock (ex. master clock) of Figure 2A has a time period  $T$ . The 15 timings of Event 0, Event 1 and Event 2 of Figure 2C are related in a manner shown in Figure 2C. To describe the timing of Event 1 with reference to Event 0, the time difference  $NT+\Delta T$  between the two events is shown in Figure 2B where  $N$  denotes the event count data,  $T$  is a reference clock period, and  $\Delta T$  denotes the event vernier data which is 20 a fraction of the reference clock period  $T$ .

The type of event is either a drive event shown in Figure 2C or a sampling (strobe) event shown in Figure 2D. A drive event drives a tester pin or a DUT input pin to a specific voltage level. A strobe event samples the output 25 of the DUT pin at its timing. Ordinarily, a strobe waveform has no or almost no pulse width because it defines a single timing for sampling the output of DUT. However, as shown in Figure 20D, there is another type of strobe having a significantly large pulse width, i.e., a window strobe, which 30 is one of the subjects of the present invention.

As noted above, in an event based test system, the event data in the event memory is expressed by a time difference between the current event and the previous event. Thus, to produce events according to the event data, an event based 35 test system must be able to calculate the sum of the delays

of each event up to the current event. This requires a logic in the test system to keep counting of the delay times expressed in the event count data and the event vernier data from the event memory 30.

5 In the U.S. Patent Nos. 6,360,343 and 6,557,133 and U.S. Application No. 10/318,959, owned by the same assignee of this invention, it is disclosed an event summing and scaling logic for calculating a timing of the current event using the event data from the event memory. In the event summing and 10 scaling logic disclosed in the prior inventions, however, high speed reproduction of events was not fully established with use of pipeline processing. Further, compression technology is used for storing the event data in the event memory for saving the memory space. In the event summing and 15 scaling logic disclosed in the prior inventions, high speed processing of decompressed vernier events is not fully established with use of parallel pipelines.

Therefore, what is needed is an event processing apparatus and method for a high speed event based test system 20 which is able to perform high speed event timing processing with use of pipeline structure.

#### Summary of the Invention

It is, therefore, an object of the present invention to 25 provide a high speed event based semiconductor test system for producing test vectors at high speed with use of an event pipeline and vernier summation logic.

It is another object of the present invention to provide an architecture of the event pipeline and vernier summing 30 logic having a plurality of pipelines for processing the decompressed vernier data in parallel.

It is a further object of the present invention to provide an architecture of window strobe logic which differentiates a window strobe event from other events, and 35 effectively generates a window strobe enable signal.

More specifically, the event pipeline and summing apparatus of the present invention is comprised of: an event count delay logic which produces a gross delay of event count data, which is an integral part of the event data, by 5 counting a clock for a number of time defined by the event count data; a vernier data decompression logic which reproduces event vernier data which is a fractional part of the event data; an event vernier summing logic which produces event vernier sum data by summing the vernier data from the 10 vernier data decompression logic; and an event scaling logic which changes the event count data from the event count delay logic and the event vernier data from the event vernier summing logic in proportion to a scale factor.

In the event pipeline and summing apparatus, two or more 15 pipelines are incorporated at least in the event vernier summing logic for processing the event vernier data in parallel. The event pipeline and summing apparatus further includes a window strobe logic which causes to generate a window strobe when event data of two consecutive events match 20 with one another.

In the preferred embodiment, the event count data for each event is configured by one or more words where each word of event count data is stored in a different address of the event memory. The event vernier data for each event is 25 configured by vernier delay data and event type data. The event vernier data for each event is divided into one or more segments, and each segment of event vernier data is stored in the same or different address of the event memory.

The event count delay logic includes an event counter 30 which loads the event count data and down-counts the event count data by the clock and produces a terminal count signal when a count result reaches a predetermined value, and an event count state machine which controls an overall operation of the event pipeline and summing logic including a process 35 for loading the event count data into the event counter and

a process for generating an event trigger signal in response to the terminal count signal from the event counter.

The event vernier data decompression logic includes a plurality of pre-fetch registers to pre-fetch the one or more segments of the event vernier data, a plurality of loop storage registers which store the vernier data from the pre-fetch registers for performing a loop operation on the segments of the event vernier data, and a vernier data decompression state machine which controls an operation of the vernier data decompression including at least an operation of the pre-fetch registers and loop storage registers.

The event vernier summing logic includes a base accumulator which accumulates vernier delays of the base verniers for all of previous and current events, a plurality of accumulators which accumulate vernier delays of other verniers for all of previous and current events on an accumulated result of the base verniers from the base accumulator; and a carry-sum state machine which controls an overall operation of the event vernier summing logic including sending an instruction to the event scaling logic to insert one cycle of wait state into a current event count cycle when a carry arises in accumulating the vernier delays.

The event scaling logic includes an event vernier scaling logic which produces an event enable signal for each pipeline by scaling the vernier sum data from the event vernier summing logic based on the scale factor, and an event count scaling logic which produces an event clock based on the scale factor and provides the event clock to the event count delay logic.

The event count scaling logic includes a scaling counter logic for up-counting the clock when the event count scaling starts, a comparator which compares an output of the scaling counter logic and the scale factor and produces a terminal count signal when the output of the scaling counter logic

reaches the value which is one less than the scale factor, and an AND logic which produces the event clock based on the terminal count signal from the comparator and an extra cycle request from the event vernier summing logic.

5 Another aspect of the present invention is an event pipeline and summing method for an event based test system. The event pipeline and summing method is configured by various steps for performing the functions in the event pipeline and summing apparatus noted above.

10 According to the present invention, the event processing for a high speed event based test system can be effectively performed to produce the drive events and strobe events. The event data are compressed by dividing into two or more small words or segments and processed through two or more pipelines

15 in a parallel fashion. The decompression, summing and scaling processes are conducted through the pipeline structure of the present invention. The event pipeline and summing logic also includes the window strobe logic for interpreting the event data and generating the window strobe.

20 As a result, the event pipeline and summation logic of the present invention achieves the high speed event processing and high operational stability in the event based test system.

25 Brief Description of the Drawings

Figure 1 is a schematic block diagram showing a basic structure of an event based test system for implementing the event pipeline and summing method and apparatus of the present invention.

30 Figures 2A-2D are timing charts showing a basic relationship between a reference clock and timings of events in the event based test system.

35 Figure 3 is a block diagram showing a basic structure of the event pipeline and summing apparatus of the present invention.

Figure 4A is a timing charts showing an example of series of events, and Figure 4B is a schematic block diagram showing a concept of event data structure stored in an event memory which describe events for generating the series of 5 events shown in Figure 4B.

Figure 5 is a block diagram showing a basic structure of the event count delay unit and event vernier summing unit of Figure 3B for producing the waveform of Figure 4A with use of the event data of Figure 4B.

10 Figures 6A-6C show an example of event data compression method, where Figure 6A is a timing chart showing an example of series of events, Figure 6B is an example of structure of event data for generating the waveform of Figure 6A without compression, and Figure 6C is an example of data structure 15 of event data incorporating a compression technology for generating the waveform of Figure 6A.

Figure 7 is a schematic block diagram showing a basic structure of the event count delay logic in the event pipeline and summing logic of the present invention for 20 summing the integral part of the event data.

Figure 8 is a state diagram showing an example of operation of the event count state machine in the event count delay logic of Figure 7.

Figure 9 is a diagram showing an example of data formats 25 of the event count data from the event count memory to be loaded in the event counter of Figure 7.

Figure 10 is a diagram showing an example of data formats of the event vernier data in the event vernier memory using the compression technology.

30 Figure 11 is a diagram showing a relationship between the event data format in Figure 9 and the vernier data format in Figure 10 for each event.

Figures 12A-12B are block diagrams showing a basic architecture of an event vernier data decompression logic of 35 Figure 3B wherein Figure 12A shows an event vernier state

machine and Figure 12B shows a parallel circuit arrangement for decompressing one or more pieces of vernier data for each event.

Figure 13 is a state diagram showing an example of basic 5 operation of the event vernier data decompression state machine incorporated in the event vernier data decompression logic of Figures 12A-12B.

Figure 14 is a block diagram showing an example of structure in the event vernier summing logic of Figure 3B for 10 accumulating the vernier data of the series of events through the parallel pipelines.

Figure 15 is a schematic diagram showing a basic concept of the event scaling logic in the present invention for scaling the event count data and event vernier data.

15 Figure 16 is a block diagram showing a basic architecture of the event scaling logic in the present invention for scaling the event count data from the event count delay logic of Figure 7.

Figure 17 is a block diagram showing an example of 20 structure of the event vernier scaling logic in the present invention for scaling the event vernier data from the event vernier summing logic of Figure 14.

Figure 18 is a block diagram showing an example of structure in the event vernier scaling logic in the present 25 invention for final compare of the scale count value from the event scaling logic of Figure 16.

Figures 19A-19H are waveform charts showing an example of scaling operation by the event scaling logic of Figures 16-18 in the present invention when the scaling factor is 30 three (3).

Figures 20A-20D are timing charts showing an example of waveforms involved in the event test system for explaining a window strobe to detect a glitch like waveform in the output of the DUT.

35 Figure 21 is a schematic diagram showing an example of

event data stored in the event memory for generating the window strobe of Figure 20D.

Figure 22 is a block diagram showing an example of structure in the window strobe logic for detecting the event 5 vernier data and event type data for generating the window strobe based on such data.

Figures 23A-23B are diagrams showing an example of comparison rules by the window strobe logic of Figure 22 for detecting a window strobe.

10 Figures 24A-24B are diagrams showing an example of window strobe determinations by the window strobe logic of Figures 22 and 23 for detecting a window strobe.

Figure 25 is a block diagram showing an example of structure in a duplicate event removal logic for detecting 15 a valid window strobe.

Figure 26 is a diagram showing an example of operation for window strobe event type removals by the circuit diagram of Figure 25.

Figures 27A-27B are timing charts showing an example of 20 operation of the event pipeline and vernier summing method and apparatus of the present invention when the scale factor is one (1).

Figures 28A-28B are timing charts showing another example of operation of the event pipeline and vernier 25 summing method and apparatus of the present invention when the scale factor is one (1).

Figures 29A-29B are timing charts showing a further example of operation of the event pipeline and vernier summing method and apparatus of the present invention when 30 the scale factor is two (2).

Figures 30A-30B are timing charts showing a further example of operation of the event pipeline and vernier summing method and apparatus of the present invention when the scale factor is two (2).

35 Figures 31A-31B are timing charts showing a further

example of operation of the event pipeline and vernier summing method and apparatus of the present invention when the scale factor is two (2).

5

#### Detailed Description of the Invention

Embodiments of the present invention will be described with reference to the accompanying drawings. The event pipeline and summing (EVP) method and apparatus of the present invention is designed to perform high speed event 10 timing processing with use of a pipeline structure. The event pipeline and summing method and apparatus of the present invention is implemented mainly by the event summing and scaling logic 22 and the event address controller 18 in the event based test system shown in Figure 1.

15

Figure 3 shows a basic configuration of the event pipeline and summing logic 33 of the present invention. The event pipeline and summing logic 33 sends instructions to the address controller 18 and receives address data therefrom. The event pipeline and summing logic 33 also receives the 20 event data from the event memory (event count memory 20 and event vernier memory 21). The event pipeline and summing logic 33 processes the event data and sends the final values of the event data to the event generator 24 which generates test vectors and strobes based on the event data for testing 25 a device under test (DUT). As noted above, the event data is composed of event count data (integral part of the clock cycle) and event vernier data (fractional part of the clock) and event type data.

30

In Figure 3, the event pipeline and summing logic 33 includes an event count delay logic 34, a vernier data decompression logic 35, an event vernier summation logic 36, an event scaling logic 37, and a window strobe logic 38. The event count delay logic 34 produces a gross delay of integral parts of the event data from the event count memory 20. The 35 vernier data decompression logic 35 reproduces the vernier

data based on the compressed vernier data from the event vernier memory 21. The event vernier summing logic 36 produces event vernier sum data by summing the vernier data from the vernier data decompression logic 35. The event 5 scaling logic 37 changes the event timing data from the event count delay logic 34 and the event vernier summing logic 36 in proportion to a scale factor. The window strobe logic 38 monitors the event type data and vernier data and produces a window strobe when predetermined conditions are met.

10 Before going into the details of the structure and operation of each logic in the event pipeline and summing logic 33 of Figure 3, the basic concept involved in the present invention is described with reference to a series of waveforms, event data for generating the waveforms, and a 15 circuit structure for processing the event data. First, the process of event timing computation is considered with reference to Figures 4A-4B and 5. Figure 4A is a waveform diagram showing a sequence of events and Figure 4B is a data table showing an example of event data stored in an event 20 memory for generating the series of events in Figure 4A. The waveforms of Figure 4A show the timing relationship among the events relative to the event clock (or main clock when scale factor is "1"). In the data table of Figure 4B, the timing data in each and every event is defined by a set of event 25 count data (integral part of reference clock) and event vernier data (fractional part of reference clock).

In the data table of Figure 4B, each of the events E0-E8 (Figure 4A) is a time difference from the immediately prior event. Such time differences are denoted by  $\Delta V_0$ ,  $\Delta V_1$ ,  $\Delta V_2$ , 30  $\dots \Delta V_8$  in the waveform chart of Figure 4A. Since each time difference is a time length between two adjacent events, such a time difference is expressed by a combination of the event count data and the event vernier data. The event count data C0-C8 is shown in a "Event Count" column and the vernier data 35 V0-V8 is shown in a "Event Vernier" column of the table.

"Event Type" column defines a type of event for each event such as "Drive Low" (1 to 0) and "Drive High" (0 to 1).

For example, the event E2 is apart from the event E1 by  $\Delta V_2$  and is defined by the event count data C2 (integral part value) and the vernier data V2 (fractional part value). Thus, the event E2 is expressed as  $\Delta V_2 = C2 \times Tp + V2$ , where Tp is a one cycle time length of the clock (main clock). Similarly, the event E3 is apart from the event E2 by  $\Delta V_3$  and is defined by the event count data C3 (integral part value) and the vernier data V3 (fractional part value). Thus, the event E3 is expressed as  $\Delta V_3 = C3 \times Tp + V3$ . It should be noted that, for producing the events at the prescribed timings in the manner of Figure 4A, such time differences  $\Delta V_0, \Delta V_1, \Delta V_2, \Delta V_3, \dots$  between the events must be summed up to determine the timing of the current event.

Figure 5 is a block diagram showing a simplified structure in the event summing logic for summing the event data shown in Figure 4B. Namely, the event summing logic reproduces the timing relationship shown in the event waveforms of Figure 4A by computing the event timings. The event summing logic includes an accumulator formed of an adder 43 and a register 44, an event count logic (event counter) 42 and an event processing state machine 41. The clock is commonly supplied to the state machine 41, the event count logic 42 and the register 44. The event count data from the event memory is provided to the event count logic 42, and the event vernier data from the event memory is provided to the adder 43.

The event count logic 42 is, for example, a down counter which is preset by a numerical value expressed by the event count data. Thus, the event count logic 42 produces a terminal count pulse when the count result reaches a predetermined value such as zero by counting the number of processing clock. Upon receiving the terminal count pulse from the event count logic 42, the event processing state

machine 41 produces valid data enable (event trigger, event enable) which is sent to the accumulator in synchronism with the processing clock. The accumulator accumulates the vernier data, and upon receiving the valid data enable from 5 the event processing state machine 41, it produces the accumulated vernier data (vernier sum data). Thus, the accumulated vernier data is supplied to the event generator 24 at the timing defined by the event count data (valid data enable). The event generator 24 has a delay circuit which 10 adds the delay time defined by the accumulated vernier data to the timing of the valid data enable.

Therefore, the event E2 for example, where the event count data is C2 and the event vernier data is V2, a terminal count pulse is produced by the event count logic 42 when 15 counting the processing clock by C2 times. Upon receiving the terminal count pulse, the event state machine 41 produces the valid data enable which is sent to the accumulator. In the accumulator, the vernier data V2 is added to the prior vernier data and the resultant accumulated vernier data is 20 produced at the timing of the valid data enable from the event state machine 41. Based on the event type data (such as drive high or drive low) from the event memory and the accumulated vernier data from the event summing logic, the event generator 24 produces the event E2 which is  $\Delta V2$  apart 25 from the event E1.

In the application of semiconductor device testing, the time difference between two events extends from several nanoseconds to several hundred milliseconds. Further, the semiconductor device testing requires a high timing 30 resolution and accuracy. Thus, a large number of bits must be used for the event data to describe the timing of each event, requiring a large capacity in the event memory. Thus, to use the memory capacity more efficiently, a compression technology is preferably incorporated for storing the event 35 data in the event memory.

Figures 6A-6C show an example of such an event data compression method. Figure 6A is a timing chart showing an example of series of events, and Figure 6B is an example of data structure of event data for generating the waveform of Figure 6A without using compression. Figure 6C is an example of data structure of event data incorporating the compression technology for generating the waveform of Figure 6A. The U.S. Patent Nos. 6,226,765 and 6,578,169 owned by the same assignee of this invention shows the details of the compression and decompression technology as well as other compression methods for an event based test system.

For generating the waveform of Figure 6A, a basic data structure such as shown in Figure 6B can be used as the event data. For simplicity of illustration, event type data is not shown in Figures 6B and 6C. In this example, for each event, a total of 27 data bits are assigned to the event count data (event count memory) and 28 data bits are assigned to the event vernier data (event vernier memory). Such a large number of bits are used for each data to cover the maximum anticipated time length and resolution. In many cases, however, each time difference between the adjacent events is much smaller than the maximum possible time length, thus a much shorter length of data bits is sufficient.

Accordingly, in the data structure of Figure 6C, a data compression (memory compaction) technology is used when storing the event data in the event memory. In this example, the event count data is configured by 1-4 words where one word is composed of eight (8) bits. One word of event count data is stored in one address of the event count memory. The event vernier data is configured by four vernier delays each being seven (7) bits. One or more vernier delays may be used for one event and the maximum of four vernier delays will be assigned to one event. In this manner, by using two or more small words in the event count data and event vernier data, the overall amount of data can be significantly decreased

since the maximum number of words are not frequently necessary in the actual application.

Now, each logic in the event pipeline and summing apparatus 33 of Figure 3 is explained in more detail. Figure 5 7 is a block diagram showing a configuration of the event count delay logic 34 in Figure 3. The event count delay logic 34 provides a gross delay based on the test system's event clock. More specifically, the event count delay represents the number of integral event clock counts between 10 events at a device under test (DUT) and the number of vernier events that will be triggered. As noted above, the vernier event values provide a fine delay (less than one clock) following the final clock cycle of the event count (delay time defined by the sum of integral clock counts).

15 Within the context of the present invention, an event clock is a processing rate of the event data, and a master clock is a clock that the hardware uses to conduct its event processing. The repetition rate of the event clock can be the same as that of the master clock. As will be described 20 later, the event clock can be created by multiplying a scaling factor with the master clock. In other words, the hardware components are processed by the rate of the master clock where the event timings are modified by the rate of the event clock.

25 In Figure 7, the event count delay logic 34 includes an event count state machine (ECS) 41 and a 27-bit event counter 42, which is basically the same as that shown in Figure 5. Throughout the description of the present invention, all clock inputs use the master clock unless otherwise specified.

30 The event count state machine 41 is a master controller for an overall operation of the event pipeline and summing logic (EVP) 33 in Figure 3. Namely, the event count state machine 41 operates as a master controller of the event pipeline and summing logic 33, and determines the number of event clock 35 delays between vernier events.

The event count state machine (ECS) 41 controls the operation of both the event counter 42 and an event vernier pipeline (ex. vernier data decompression 35 and event vernier summing 36 of Figure 3B). The preferred embodiment of the 5 present invention incorporates the compression method similar to the example shown in Figure 6C as will be described later. Thus, the event count state machine 41 controls the process of loading the event count data into the event counter 42. Specifically, the event count state machine 41 provides the 10 following functions:

(1) Loading of the event data to the event counter 42 based on the state of "start" and "continue" signals which are defined in Table 1.

15

Table 1

Start	Continue	Operation
0	0	Return to Idle.
0	1	Return to Idle.
1	0	Begin processing and Initialize EVP.
20	1	Continue processing without initializing EVP.

(2) Handshaking with an event vernier state machine (Figure 14) in the event vernier summing logic 36 and an event scaling state machine (not shown) in the event scaling 25 logic 37 shown in the event pipeline and summing logic 33 of Figure 3.

(3) Generating an event trigger signal that acts as an master enable for the vernier data. As will be described in detail later, the event trigger signal is produced by summing 30 the event count data while incorporating an additional delay when there is a carry over as a result of event vernier summing or event vernier scaling.

(4) Generating pipeline control signals to increment the

vernier pipelines at the end of each event count.

(5) Fully controlling the event count RAM's address counters (address controller 18) at all times during either the start or continue operation.

5       (6) Generation of the status signal "Busy" that is true during normal operations. The busy signal stays true until the last data value has been flushed from the EVP (event pipeline and summing logic 33) pipeline at the end of data processing. The event count state machine provides means to

10      send a signal to the event based test system to inform that the EVP pipeline is flushed. This operation does not require a specific state of the event count state machine 41.

The event count state machine 41 uses handshaking with other state machines in the event pipeline and summing logic 33 in two ways. The first is to simply signal the start of a new event count. This operation is primarily confined to the event vernier state machine (Figure 14). The second type of handshaking causes the state machine to insert wait states into its processing cycle. This operation occurs between the event count state machine 41 and the event scaling logic (Figures 16-18).

Figure 8 is a state diagram showing a basic flow of operation of the event count state machine 41. The states in the diagram are defined as follows:

25      The "Idle" state 51 holds the current state of the event pipeline and summing logic (EVP) 33 between each data processing session. The next processing session may begin as either the start of processing or a continuation of processing.

30      The "Initialize Pipeline" state 52 initializes the EVP pipelines in preparation for the next valid piece of data. The initialization depends on the operation required. Thus, the initialization may require the entire EVP pipelines to be re-initialized or it may simply require that the pipelines

35      resume previous data processing. The signals "start" and

"continue" determine the operation required.

The "Event Count Load" state 53 loads the event delay counter 42 based on the data from the event count memory 20. The loading operation may consists of 1 to 4 bytes of event 5 count data (Figure 9). A load of an event count of either 0 or 1 requires the event count state machine 41 to perform another load operation during the next event clock cycle. This will continue until the event count becomes greater than 1 (bit [7] in Figure 9).

10 The "Event Delay Count" state 54 provides the means to add delay to each event based on the terminal count signals from the event counter 42.

15 Although the state diagram does not show the pipeline enable (Figure 7) from the event scaling logic, this signal acts as a pipeline clock enable to the event count state machine 41. The pipeline enable from the event count scaling logic 37 converts the operation of the event count state machine 41 from being based on the master clock cycles to being based on the event clock cycles. In other words, the 20 pipeline enable has a repetition rate of the event clock.

Referring back to the block diagram of Figure 7, in the preferred embodiment, the event counter 42 consists of a 27 bit down counter. The event count state machine (ECS) 41 loads the counter based upon the formats of delay data stored 25 in the event count memory 20. As noted above with reference to Figures 6A-6C, for effectively using the event memory, it is preferable to describe each event data by one or more small words.

Such an example is shown in Figures 9-11. In the 30 example of Figures 7 and 9-11, the event count data possibly have four types of formats: single word, double words, triple words and quad words, i.e., up to 4 words. Thus, in the case where a particular event count data is configured by triple words, a data loading operation of 8 bits (one word) from the 35 event count memory 20 to the event counter 42 will be

repeated three times.

Figure 9 shows an example of data structure in the event count memory 20 in the present invention. In this example, an 8-bit word is configured by 5-bit count data COUNT[4:0], 5 2-bit vernier number data EVCNT[6:5] and a 1-bit flag[7]. The COUNT data shows a number of clock cycle to delay for a particular event, i.e., integral part of the event data. The EVCNT data shows a number of vernier events in the processing cycle. Because of the compression method shown in Figures 10 6C and 9-11, it is necessary to know as to how many pieces of vernier data in the particular address of the event memory for a particular event. The EVCNT data shows such information. The flag[7] is to distinguish the types of event count data by indicating whether there is a remaining 15 word (flag 0) or it is the last word (flag 1).

For loading the event count data of Figure 9 to the event counter 42, the address controller 18 (Figures 3) provides the address to the event count memory 20. The event count state machine 41 issues an address increment signal to 20 the address controller 18 to increment to the next address following each load of the event count data. The event count data is assumed to have been reduced by the number of load operations required. For single byte count values, no reduction is necessary because this operation does not 25 require the event counter 42 to pause between counts. For two or more byte counts, each additional byte requires the counter to wait for one additional event clock cycle. For example, a quad word load of event count data implies that the entire value has been reduced by three event clock count 30 cycles by software prior to being loaded into the event count memory 20. For all count cycles, the unused bits of the event counter 42 will be forced to zero during the first data load cycle.

The event vernier data decompression logic 35 in Figure 35 3 is described in more detail with reference to Figures 10-11

and 12A-12B. The event vernier data decompression logic 35 performs the function of decompressing the vernier data stored in the event vernier memory 21. For effective use of the memory capacity, the compression technology similar to 5 that shown in Figure 6C is used in the preferred embodiment. Namely, the event vernier data is divided into one or more relatively small bits of data so that each event may have from 1 to 4 vernier delays (first to fourth vernier data). Each vernier data has a vernier delay data (7 bits) and one 10 event type data (3 bits). The event count memory 20 provides the number of vernier delays in each event clock cycle as the event count parameter EVCNT[1:0] as shown in Figure 9.

The vernier data is sequentially stored in the event vernier memory 21 in the manner shown in Figure 6C and Figure 15 10. Namely, each address of the event vernier memory stores four words of vernier data. In the present invention, such vernier data are processed through four pipelines in a parallel fashion as will be described later. Thus, in the event vernier memory of Figure 10, the event vernier data is 20 sequentially stored for respective pipelines starting at a vernier pipeline 0, and continuing to vernier pipelines 1, 2, and 3.

In the example of Figure 10, Event 0 has three vernier delays (Vernier 0-2) and Event 1 has four vernier delays 25 (Vernier 0-3) while Event 2 has one vernier delay (Vernier 0). Figure 10 shows that one or more vernier delays may cross the memory address boundaries. For example, Vernier 0 of Event 1 is in the address 0 while other Verniers 1-3 of Event 1 are in the address 1 of the event vernier memory. 30 However, each event count delay may only require a one-clock cycle delay. Thus, the event vernier data decompression logic 35 (Figures 12A-12B) must pre-fetch the vernier data from at least two memory addresses of the event memory in order to insure that all vernier data is available for each 35 event during each master clock cycle. Figure 10 also

demonstrates that two or more events may use one vernier address. For example, event data for Event 3, Event 4 and Event 5 are stored in the address 2 of the vernier memory. This means that the address pointer of the event count memory 5 20 will have no relationship to the address pointer of the event vernier memory 21, i.e., independent from one another.

Figure 11 shows the relationship between the event data and the event vernier data for each event. For simplicity, this example assumes that the event count memory is loaded 10 with single byte of event count data. As noted above, EVCNT indicates a number of vernier data involved in each event. ECR address indicates the addresses of the event count memory (event count RAM) and EVR address indicates the addresses of the event vernier memory (event vernier RAM). The vernier 15 data are allocated to vernier pipelines 0-3.

In Figure 11, the valid vernier pipeline data are listed for each event as defined in the event vernier data format of Figure 10. In this example, Event 1 and Event 5 show how event vernier data may cross the addresses of the event 20 vernier memory. Similarly, the addresses of the event count memory closely correspond to the event number, where as, every address of the event vernier memory contains vernier data for multiple events.

Figures 12A-12B illustrate the basic architecture of the 25 event vernier data decompression logic 35. The event vernier data decompression logic 35 is comprised of an event vernier data compression state machine 56, two banks of pre-fetch queue registers and two banks of loop storage registers. The event vernier data compression state machine 56 in Figure 12A 30 controls an overall operation of the event vernier decompression. Figure 12B shows that four vernier data can be provided to the corresponding pipelines 0-3 in parallel where the vernier pre-fetch registers fetch the event vernier data based on the vernier number data EVCNT[1:0] from the 35 event counter memory 20. In this example, each vernier data

bus provides seven bits of vernier delay data and three bits of event type data. As noted above, since the four pipelines are configured in this logic, the pre-fetch queue registers and loop storage registers are divided into four to the 5 corresponding pipelines.

As noted above, since there are times when the vernier data for each event are required to retrieve from two separate memory addresses. It is not physically possible to retrieve data from two separate addresses simultaneously when 10 using a single port RAM. Therefore, a pre-fetch must be performed that retrieves the contents of two addresses during initialization. Thus, when a multiport RAM is used as an event vernier memory, the pre-fetch queue registers may not be necessary. When looping, the loop registers are used to 15 restore the state of the pre-fetch registers. Such a restoration process is a requirement for the proper operation of the decompression logic.

In the event vernier data decompression logic 35, the event vernier data decompression state machine 56 is 20 responsible for maintaining an event pointer that tracks vernier 0 for each event. As shown in Figures 10-11, vernier 0 represents the base vernier for each event. The event vernier data decompression state machine 56 is responsible for handshaking with the event count state machine 41 (Figure 25 7) to determine the start of each new event count. The event vernier data decompression state machine 56 generates the necessary enables to mark all valid vernier pipelines, and fully controls the event vernier address counters at all times during either "start" or "continue" operation.

30 The event vernier data decompression state machine 56 is also responsible for saving the state of both the event pointer and each vernier pipeline prior to any loop operation. This is due to the compression of the vernier data as shown in Figures 10 and 11. The loop control signals 35 are defined as shown in Table 2.

Table 2

LOOP_STORE	LOOP_INIT	Operation
0	0	Normal processing
0	1	Restore the event pointer and pipeline data
5	1	Store the event pointer and pipeline data
1	1	Invalid

In the loop operation, it should be noted that the longest vernier value (of the vernier 1, 2, or 3) from each event 10 must be separated from the next vernier 0 by at least one event clock during loop operations. This is not a requirement for non-looping operations.

The event vernier pre-fetch queue registers consists of two banks of registers as noted above. Each bank can store 15 up to four event vernier data consisting of 10 bits each (7 bits of vernier data and 3 bits of event type data). The loop storage registers provide storage equal in size to the pre-fetch registers. The vernier data decompression state machine 56 provides the controls to load or select each of 20 these register sets.

Figure 13 is a state diagram showing the basic flow of operations of the event vernier data decompression state machine 35. The states in the diagram are defined as follows:

25 The "Idle" state 61 holds the current state of the pre-fetch queue controls between each data processing session. The next processing session may begin as either the start of processing or a continuation of processing.

The "Initialize Pre-Fetch Queue" state 62 initializes 30 the event vernier pre-fetch queue in preparation for the next valid piece of data. This initialization may require the entire pre-fetch queue registers to be re-initialized or it may simply require that the queue resume the previous data

processing. The signals "start" and "continue" determine the operation required.

The "Pre-Fetch Queue Reload" state 63 loads the event vernier pre-fetch register banks based on the EVCNT[1:0] data 5 from the event count memory 20 indicating the number of vernier delays involved in the particular event. More specifically, the pre-fetch queue register acts as a ping-pong buffer where the banks are alternately reloaded. Storage and retrieval of data for loop operations may also 10 be performed in this state. Loop data retrieval occurs when the LOOP\_INT signal (Table 2) has been asserted, and consists of enabling a series of select bits until the pre-fetch queue bank(s) are reloaded from the event vernier memory 21. Similarly, the vernier pipeline pointer is automatically 15 restored during the assertion of the LOOP\_INT signal. The loop operations do not require a separate state.

The event vernier summing logic 36 in Figure 3 is described in detail with reference to Figure 14. The event vernier summation logic 36 is responsible for correctly 20 determining the vernier delays within a clock cycle. The event vernier summation is condensed to calculating the fractional delays within an event cycle as represented by the event vernier data from the event vernier memory 21. As shown in Figures 10 and 11, there are two types of vernier 25 delay possible since the preferred embodiments incorporates the compression technology. The first is vernier 0 delay value ( $\Delta V_{n0}$ ) where "n" indicates a n-th event. The vernier 0 delay provides the base delay of each event within a clock cycle. The remaining vernier delay values ( $\Delta V_{n1}$ ,  $\Delta V_{n2}$ ,  $\Delta V_{n3}$ ) 30 are added to this base value for each event. Thus, an overall vernier delay for each event is the sum of the vernier 0 value and the remaining vernier delay values. For example, for Event 1, an overall vernier delay  $\Delta V_1$  is composed of the sum of a vernier 0 delay  $\Delta V_{10}$ , and remaining 35 vernier delays  $\Delta V_{n1}$ ,  $\Delta V_{n2}$ , and  $\Delta V_{n3}$ . It should be noted that

the event vernier summing logic 36 is to obtain a sum of all of the vernier delays of all of the previous events and the current event.

Figure 14 shows the basic architecture of the event vernier summation logic 36. All clock inputs use the master clock unless otherwise specified. The event vernier summation logic 36 consists of a vernier 0 accumulation logic, a vernier carry-sum state machine, and a vernier pipeline sum logic. The vernier 0 accumulation logic includes an accumulator consisting of an ALU (arithmetic logic unit) 75 and a register for accumulation of each vernier 0 delay through a multiplexer (MUX) 73 of each event. In this example, only the lower 6 bits of the accumulation are maintained.

When a carry is detected during the accumulation, the carry-sum state machine 71 must determine when to insert an additional clock cycle. This means that an extra cycle must be added to the event count sum when the accumulated event vernier exceeds one cycle of the clock. The carry-sum state machine 71 handshakes with a scaling counter logic 91 in Figure 16 to insert one wait state into its current event count cycle. This has the effect of adding one additional event clock of delay between the current event and the next event. The only exception to adding one clock for each carry detected occurs when the event has a zero event count delay. A carry is meaningless under this condition since a clock cycle is already inserted between the zero event count delay and the next event.

The final operation performed by the event vernier summation logic 36 is to add the accumulated vernier 0 delay ( $\Delta V_{0\ sum}$ ) to each of the remaining vernier delays ( $\Delta V_{n1}$ ,  $\Delta V_{n2}$  and  $\Delta V_{n3}$ ). The vernier summing logic 36 includes four pipelines 0-3 each having an arithmetic logic unit (ALU) for adding the accumulated vernier 0 delay to the remaining vernier delays. This example shows that each pipeline has

five cells (Cell 1-5) through which the data is sequentially shifted by one cell at each master clock. The above noted process produces the final vernier delay (vernier sum data) for each vernier pipeline during non-scaling operations.

5        The event vernier summing logic of Figure 14 performs no operation on the event type data of any of the vernier pipelines. Although not shown, the event type data is simply passed down the summation pipeline in order to maintain data alignment with the vernier data.

10       The event scaling logic 37 in Figure 3 is described in detail with reference to Figures 15-19. Figure 15 is a simplified diagram showing the basic concept of the event scaling logic and the relationship with the event summing logic. An event summing logic 82 includes an event count summing 83 and an event vernier summing 84. The event count summing 83 corresponds to the event count delay 34 (Figure 7) and the event vernier summing 84 corresponds to the event vernier summing 36 (Figure 14). An event scaling logic 86 includes multipliers 88 and 89 to multiply the event count sum and event vernier sum by a scale factor. The scaled data is combined by an adder 87 is supplied to the event generator 24 (Figure 3).

As noted above, the event scaling logic 37 provides the means to multiply the delay between events. In the preferred embodiment, the multiply factor is configured by 8 bits, which allows the delays between events to be scaled up to 256 times. As shown in Figure 15, the scaling has two parts: the event count scaling (multiplier 88) and the event vernier scaling (multiplier 89). The event count scaling is to scale 25 the accumulated event count data by a scaling factor and the event vernier scaling is to scale the accumulated event vernier data by the scaling factor.

30       Figure 16 illustrates the basic architecture of the event count scaling logic. The event count scaling logic includes a scaling counter 91, a comparator 93, a scale

factor register 95, and an AND logic. The scaling counter 91 is typically an up-counter for up-counting the number of master clock. The comparator 93 compares the output of the scaling counter 91 and the scaling factor from the register 95. In this example, the comparator 93 produces a terminal count signal when the count result A reaches less than one of the scaling factor B, i.e.,  $A=B-1$  or  $\#C$ . The scale factor register 95 stores 8 bits of scaling factor as noted above. The AND logic produces an event clock (event pipeline enable) based on the terminal count signal from the comparator 93 and the extra cycle delay from the carry-sum state machine 71 in the event vernier summing logic (Figure 14).

Basically, for scaling event data, the event count scaling logic of Figure 16 produces an event clock which has a time period of the scale factor times of the master clock. For example, to increase the event timings by two times, the scale factor is two (2). In this case, the event count scaling logic of Figure 16 produces an event clock having a time period two times of that of the master clock. The event clock is generated through the AND logic based on the terminal count signal from the comparator 93. The event clock is provided to the event count state machine 41 in the event count delay logic of Figure 7, thereby producing the event trigger signal to the event vernier summing logic (Figure 14) based on the event clock.

In other words, the terminal count signal from the comparator 93 is the product of comparing the current scale cycle count to the value of the scale factor less than one. This operation allows signals such as a pipeline enable signal to occur during the terminal count cycle of the scale counter logic. However, this produces an offset between the scale count value and the scale enable signal of one clock cycle. Therefore, the scale enable signal should be valid on the last counter's cycle ( $m$ ) and not the second to the last cycle ( $m-1$ ).

The scale mode signal is simply the inverse of the scale enable signal. The scale mode signal loads the first value of the vernier accumulator logic for the next scaled event clock cycle. The accumulator logic is discussed in more 5 detail later.

The block diagram of Figure 16 shows no control connections from either the event count state machine or the event vernier state machine. The scale counter logic 91 is controlled by the scale enable signal which is a static bit 10 held in a register in the address controller (AC) 18. This bit is set or reset before processing begins. Thus, all of the output signals are valid prior to the start of event data processing. The scale enable signal should be disabled when the scale factor register is updated. This prevents the 15 scaling counter logic 91 from potentially incrementing through its full 256-count range before using the new scaling factor.

The event count scaling operation is entirely controlled by the scale counter logic 91 through the signals such as 20 event pipeline enable, pipeline clock enable to the event count state machine (event clock), and pipeline clock enable to the event vernier state machine (event clock). These signals provide the pipeline clock enables that insure that no data operation will advance faster than at a scaled, event 25 clock period.

The event count scaling logic consists of inserting wait states into the event count state machine 41 (Figure 7) equivalent to the scaling factor. For example, a scaling factor of "2" means that each event clock cycle will now use 30 two master clock cycles. A scaling factor of "3" means that each event clock cycle will now use three master clock cycles, etc. These wait states are generated by the scale counter logic (up-counter) 91 in Figure 16. The scale counter logic 91 provides both the means to insert wait 35 states and the means to give the vernier delay scaling logic

a way to determine when each vernier delay is valid (ex. event trigger).

The event count scaling logic of Figure 16 generates a period signal which is an event cycle signal. The period signal marks the beginning of each event clock cycle. For non-scaled operations, the event clock cycle equals the master clock cycle. The period signal is always asserted during valid processing cycles only (marked by the busy signal).

10 For scaled operations, each event clock cycle equals "k" master clocks where "k" is the scale (multiplication) factor (i.e. 1, 2, 3, etc.). The period signal is only asserted during the first master clock cycle of each event clock cycle. In the preferred embodiment, the event scaling logic 15 issues two additional period pulses at the end of a processing sequence to flush the event generator pipeline.

Figures 17 and 18 show the basic architecture of the event vernier scaling logic. The vernier data are shifted through the pipelines 1-4 in the parallel fashion by the 20 timing of the master clock. Figure 17 shows the vernier data accumulator used for adding the vernier data an integer number of times. On the other hand, Figure 18 shows the 25 final compare of the scale count from the scale counter logic 91 of Figure 16 and the MSB's of the accumulator in Figure 17. The pipeline enables used in the event count scaling logic are not used in the event vernier scaling logic which is simply a data flow-through. The output from previous portions of the event pipeline and summing logic 33 already enter this logic correctly delayed in time.

30 These block diagrams in Figures 16-18 show that the scaling count value data has one fewer delays than the scale enable signal. The removal of the extra delay aligns the beginning of the scale count to the first master clock cycle following the assertion of the scale enable signal.

35 As noted above, the event count scaling logic consists

of inserting wait states into the event count state machine 41 equivalent to the scaling factor. The event vernier scaling logic of Figure 17 multiplies each vernier sum value by the scaling factor. The simplest means to multiply the 5 vernier delay value is to simply accumulate each delay value for the number of times indicated by the scale factor. For example, a scaling factor of "2" means that there will be two master clocks during each event clock. Thus, these two clocks allow each vernier delay value to be summed with 10 itself ( $1+1=2$ ). A scale factor of "3" means that each vernier delay value may be added two times ( $1+1+1=3$ ), etc. To achieve this, each accumulate cycle consists of a load 15 cycle where the delay value is simply passed. This is followed by an accumulate cycle where the delay value is added on each successive clock cycle ( $1+1+\dots+1=K$ ).

Thus, in the vernier summing logic of Figure 17, the vernier sum data from the vernier summing logic of Figure 14 is supplied to the corresponding pipelines. The first cell (Cell 5) of each pipeline is an accumulator consisting of an 20 arithmetic logic unit and a register. To multiply the vernier sum data by a scale factor "k", each accumulator repeats the accumulation cycles by " $k-1$ " times as noted above. The scaled vernier sum data are shifted out from the pipelines (Cell 9).

25 The scaled vernier sum delay values will never be greater than the event clock length. However, the scaling operation may result in the vernier delay values spanning several master clock cycles. The maximum additional delay is 8 bits or 256 possible additional master clock cycles. 30 To correctly determine the valid master clock cycle, the MSB's of the vernier delay sum must be compared to the master clock cycle number in each scaled event clock. This is done by each comparator in Figure 18 where the output of the comparator shows the result of comparing the MSB's of the 35 final vernier scale value (Vernier Sum[14:7] to the scale

count value from the event scaling logic of Figure 16. The event count scaling logic of Figure 16 generates this cycle number and passes the values, correctly pipeline aligned, to the vernier scaling logic of Figures 17 and 18.

5        Figures 19A-19H illustrate these concepts for a scaling operation when the scale factor is "3". Figure 12A shows the master clock which is the primary clock to the event pipeline and summing logic 33 of the present invention. Figure 12B shows a scale count value which is an output signal of the

10      scaling counter logic 91 in Figure 16 as the pipeline aligned count. In the preferred embodiment, since the scaling counter 91 is an up-counter, the scale count value increases at each master clock. Figure 19C shows an output of the vernier scale accumulator in Figure 17. As noted above, the

15      vernier multiply operation is performed by the accumulator where the multiply operation simply consists of loading the vernier data followed by multiple addition. Thus, for the scale factor "3", the vernier data  $V_n$ , for example, is added two times to create the scaled vernier data  $3V_n$ .

20      Figure 19D shows the final vernier scaled value which is the final result of the vernier multiply operation (Vernier Sum[14:7] in Figure 17). This result is only updated at the end of each scaled clock period. The final value must be stable prior to the scale cycle comparison

25      operation. Figure 19E shows an output of the comparator in Figure 18 which is the result of comparing the MSB's of the final vernier scale value (Vernier Sum[14:7]) to the scale count value from the event scaling logic of Figure 16. The scaled vernier data determines the master clock cycle where

30      the compare becomes valid. It can occur in any of the three master clock cycles that form a single, scaled event clock cycle.

Figure 19F shows the event trigger which marks the event clock cycle where the vernier data is valid. The event trigger signal is generated by the event count state machine

41 in Figure 7. The event trigger signal is continuously high because the diagram has been condensed to show only the final cycle of each event. A longer diagram would show this signal is unasserted until the final event clock cycle of 5 each event. Figure 19G shows the event valid signal which marks a particular vernier pipeline (pipelines 0-3) as having valid vernier data. This signal is asserted for the entire event period (including both the event count and the vernier delay) that vernier pipeline contains valid data.

10       Figure 19H shows the event enable signal which marks the event clock cycle where the vernier sum data is valid for the event generator 24 to use. This signal is generated by the combination of the scale cycle compare signal (Figure 19E), the scale enable signal (Figure 16), and the event valid 15 signal (Figure 19G). Thus, the event generator 24 (Figure 3) generates an event by adding a delay time to the event enable signal of Figure 19H where the delay time is scaled vernier sum data from the event vernier scaling logic shown in Figure 17.

20       The window strobe logic 38 in Figure 3 is described in detail with reference to Figures 20-23. Ordinarily, a strobe is a timing signal for sampling an output of the device under test, thus having no pulse width. Unlike such an ordinary strobe, a window strobe is a strobe signal having a wide 25 pulse width (window). A window strobe is useful for detecting an foreseeable signal change such as a glitch in the output of the device under test.

Timing charts of Figure 20A-20D show an example of situation where a window strobe is used. Figure 20A shows 30 a clock such as a master clock or event clock in the foregoing examples. Figure 20B shows a drive event (input stimulus) which is supplied to the device input pin. Suppose the device output pin shows a waveform as shown in Figure 20C, the pulse P1 is sampled by a timing of a strobe event 35 of Figure 20D. However, for sampling glitch like waveforms

P2 or P3 in the output, it is difficult to set the timing of the strobe. Thus, an event based test system of the present invention is designed to generate a window strobe of Figure 20D to capture such glitches more easily and accurately.

5 An example of event data for generating the window strobe is shown in Figure 21. The event numbers in the data table of Figure 21 correspond to the event numbers shown in the waveform of Figure 20D. It should be noted that, for simplicity, event type data is illustrated separately from  
10 the event vernier data, although the event type data may be included in the vernier data as in the above embodiments.

In this example, for generating the strobe (event E2), "Strobe" is written as an event type. Since it is unnecessary to define a pulse width of an ordinary strobe,  
15 the event generator 24 generates the strobe based on the event timing data and the event type data. For generating the window strobe, event type "Strobe" is specified for two or more continuous events. In Figure 21, events E4 and E5 are assigned as "Strobe". The window strobe logic 38  
20 monitors the event type data for two consecutive events and interprets that the window strobe is to be generated if there are two consecutive strobe events.

Namely, the window strobe logic 38 generates a window strobe output when two event vernier data (vernier delay and  
25 event type) match. Figure 22 illustrates an example of basic architecture of the window strobe logic 38 in the preferred embodiment of the present invention. Figure 23 illustrates an example of circuit diagram in the window strobe logic 38 for removing duplicate events. The window strobe logic 38  
30 in Figures 22 and 23 has a pipeline structure similar to the foregoing examples. This example shows the case where the window strobe is produced when both the vernier delay and event type of two events match with one another. When the window strobe is to be generated, the window strobe logic of  
35 Figure 22 produces a window strobe enable which is sent to

the scaling logic of Figure 18 which performs the final output determination for the window strobe logic.

Table 3 shows these event types which produce valid window strobes.

5

Table 3

Event Type	Valid Window Strobe	Description
0	No	No Event (Reserved)
1	No	Drive a One (H) to the DUT
10	2	Drive a Zero (L) to the DUT
	3	No output to the DUT and don't care input by DUT
15	4	Test for a One (H) by DUT
	5	Test for a Zero (L) by DUT
	6	Test for High Impedance (Z) at DUT
	7	No Event (Reserved)

The window strobe logic of Figure 22 receives event vernier data (vernier delay and event type signals) for each vernier pipeline directly from the event vernier state machine and event vernier pre-fetch queue shown in Figures 12A and 12B. Each data value is compared to all others. In the example of Figure 22, the comparison operation is conducted to determine the following:

- (1) If any two events match.
- 25 (2) If each has event type of 4, 5 or 6 (Table 3).
  - (a) All other events are not valid window strobe events and are not considered.
- (3) If event vernier is the base vernier (vernier 0).
  - (a) This only applies to vernier 0.
  - 30 (b) The base vernier is identified by signals output by the event count state machine logic.
  - (c) Check if the matching event type has a

vernier=0.

(4) If the event vernier is not the base vernier.

- (a) These are verniers 1, 2, and 3.
- (b) The base vernier is identified by signals output by the event count state machine logic.
- 5 (c) Check if both the event type and event verniers are equal.

It should be noted that, depending on the result of vernier compression, vernier 0 may reside in any of the four 10 processing pipelines. Thus, the above rules require a series of comparisons. For event type, the following comparisons are performed:

- (1) For Type 0
  - 15 (a) Is Type 0 == Type 1
  - (b) Is Type 0 == Type 2
  - (c) Is Type 0 == Type 3
- (2) For Type 1
  - (a) Is Type 1 == Type 2
  - (b) Is Type 1 == Type 3
- 20 (3) For Type 2
  - (a) Is Type 2 == Type 3

The above comparisons correspond to the six comparators in the window strobe logic of Figure 22. This comparison rule is visualized by a table of Figure 23A. The mark "X" 25 represents a comparison between the two event types. A similar matrix may be constructed for the event vernier comparisons which is shown in Figure 23B

One of the objectives of the window strobe logic is to determine if any two events have the same type. The tables 30 in Figures 23A and 23B show the possible comparisons available. In the example of Figure 22, only the comparisons to Type 0 are of interest.

In addition, a window strobe is also defined as being detected when one of the event types that match to Type 0 has 35 a corresponding vernier of zero. A logic "OR" of all of the

vernier bits can determine if the vernier is zero (at the input of the logic of Figure 22). In an "OR" operation, any input bit at t logic "1" will produce a logical "1" output. This would mark a non-zero vernier. Therefore, combining the 5 three comparisons with the four zero determinations, the window strobe may be determined.

The table of Figure 24 A shows where a window strobe would be determined for vernier 0 where the mark "W" indicates a detected window strobe. The Types on the left 10 hand column on the top have verniers equal to zero. The Types on the left hand column on the bottom have verniers that are not equal to zero.

The window strobe for verniers 1, 2, and 3 are determined in a similar way to the vernier 0 as shown in the 15 table of Figure 24B. The primary difference is that now a match between the vernier values must be made. For this determination, comparisons to Type 0 are ignored as are the determination of verniers with a value of zero. In each case, both the vernier and type must match and the Type must 20 not be Type 0.

The window strobe logic 38 generates a one-clock pulse when the event type of vernier 0 matches event types of any other vernier pipelines, and the matching vernier pipeline's delay data has a value of 0. The window strobe logic 38 also 25 generates a one-clock pulse when any two of verniers 1, 2, and 3 match on both the vernier delay and event type. In both of the cases above, one of the matching vernier pipelines is marked as not valid since no two vernier delay values may produce the same event type at exactly the same 30 time.

Thus, such duplicate events are removed by the circuitry shown in Figure 25. In this example, the removal operation is performed according to the table of Figure 26. The rule for this operation is that one of the two events must be 35 removed. This table chooses the higher numbered Type and

vernier to be eliminated. What this determination generates are a series of event enables. The event types and verniers will have the corresponding event enable signals disabled. A logical "AND" of the enable signals with the event valid 5 signals determines which event data values will be invalidated (AND gates in Figure 26). This effectively removes them from generating any operations in the event generator.

In each of these cases, one of the matching vernier 10 pipelines will remain valid. This vernier pipeline will have its corresponding window strobe enable signal asserted. The window strobe enable signal marks both the vernier and the type of event that the window strobe is associated with. All 15 of the rules outlined above only apply to valid window strobe event types.

As shown in Figure 18, the window strobe logic 38 synchronizes the window strobe output to the vernier data that generates the window strobe condition. Accordingly, during normal operations, all vernier delay and event types 20 are valid in the same clock cycle. Thus, all window strobes will be valid at the same point in each event. During scaling operations, the vernier values may be spread across many master clock cycles. Thus, window strobes may occur at any point in the scaled event clock cycle, and will 25 correspond to the triggering vernier data.

Figures 27A-27B to Figures 31A-31B are timing diagrams showing examples of operation in the present invention. The timing diagrams show the following signals:

"M\_CLK": a master clock.  
30 "START": a start signal which signals the beginning of summing and scaling processing. All state machines are to re-initialize all pipe lines.

"CONTINUE": a continue signal which signals that all processing should resume. No initialization is required of 35 the pipeline logic.

1        "ECR\_ADR[17:0]": address data on event count memory  
2        address bus.

3        "ECR\_AP\_INC": event count memory address pointer  
4        increment. This signal increments the event count address  
5        pointer.

6        "ECR\_CNTR[26:0)": an event counter count value (event  
7        counter 42 in Figure 7). The event counter 42 is a 27-bit  
8        counter into which up to four segments of event count data  
9        will be loaded.

10       "ECR\_CNT\_LD[3:0)": event counter load strobes (event  
11       count state machine 41 and event counter 42 Figure 7). The  
12       event counter 42 has four loadable segments (single word to  
13       quad word in Figure 9).

14       "EVT\_PIPE\_EN": main event vernier pipeline enable (input  
15       of event vernier state machine 56 in Figure 12A).

16       "ECR\_CNTR\_TC": an event counter's terminal count output  
17       (output of event counter 42 in Figure 7). The terminal count  
18       for this counter occurs at "2" in Figures 29A-31B.

19       "EVT\_TRIG": an event trigger signal (output of event  
20       count state machine 41 in Figure 7, and input of event  
21       scaling logic in Figure 18). This is the main enable from  
22       the event count state machine that enables the output of  
23       vernier data.

24       "EVR\_ADR[17:0)": address data on event vernier memory  
25       address bus.

26       "EVR\_AP\_INC": event vernier memory address pointer  
27       increment. This signal increments the event vernier address  
28       pointer.

29       "EVNT\_CNT[1:0)": data showing a number of event verniers  
30       (EVCNT in Figure 9). This is the number of vernier events  
31       in this event count cycle.

32       "EVR\_PTR[2:0)": an event vernier memory pointer used by  
33       the pre-fetch logic for determining the vernier pipeline  
34       containing vernier 0.

35       "EVR\_PREF\_LD[1:0)": event vernier pre-fetch load enable.

These signals control the loading of the event vernier pre-fetch registers (Figure 12B).

5 "SCALE\_MODE": a scale mode signal (output of event count scaling logic in Figure 16). During scaling operations, this signal controls the loading of the scaling accumulators for each vernier pipeline.

10 "ZERO\_CY\_FLG": an output from the event count state machine 41 in Figure 7 to the carry-sum state machine 71 in Figure 14. This flag means that the carry-sum state machine should not add a cycle if a carry is detected.

"ONE\_CY\_FLG": a combinational signal that flags the present cycle as containing a single event clock count.

15 "EXTRA\_CY\_EN": an output from the carry-sum state machine 71 in Figure 14 to the scale counter logic 93 in Figure 16 that requests the addition of one event clock count.

"CARRY\_SUM": an output from the vernier 0 accumulator in Figure 14 that indicates that there has been a carry bit generated.

20 "VER\_DAT\_nP[6:0)": vernier data for a pipeline "n" (Figure 12B. This data includes both delay and event type.

25 "VER\_ENBL\_nP": vernier data enable for a pipeline "n". This is equivalent to the event enable of Figure 19H for the event generator 24 to generates an event by adding the delay time specified by the scaled vernier sum data.

"PERIOD\_T": a period signal used to mark the start of a scaled clock cycle (output of Figure 16) and to support the event generator operations.

30 "WSTB": a window strobe (output of Figure 18). The window strobe is generated when the event type and vernier delay of two consecutive events match the predetermined conditions.

35 Figures 27A-27B and 28A-28B show examples of how the event count and event vernier pipeline should operate. In this example, the process starts at START by initialization

of operations. The address ECR\_ADR[17:0] for the event count memory 20 is incremented by the increment signal ECR\_AP\_INC. The address EVR\_ADR[17:0] for the event vernier memory 21 is incremented by the increment signal EVR\_AP\_INC. The event 5 counter 42 loads and processes one, two, three or four bytes event count data formats "ECR\_CNTR[26:0]" in response to event counter load strobes ECR\_CNT\_LD[3:0].

By counting the clock by a number of times specified in the event count data, the event counter 42 produces a 10 terminal count output "ECR\_CNTR\_TC" which is applied to the event count state machine 41. In response, the event count state machine 41 produces the event trigger signal "EVT\_TRIG" which is sent to the carry-sum state machine 71 for event vernier summing (Figure 14) and event scaling logic (Figure 15: 18) for enabling the output of vernier data.

The number of vernier events in the particular event cycle is described by the "EVNT\_CNT[1:0]" as a part of the event count data (Figure 9). Based on this data, the event vernier memory pointer determines the vernier pipeline 20 containing vernier 0 for the pre-fetch register "EVR\_PTR[2:0]". Thus, vernier data are loaded in the event vernier pre-fetch registers (Figure 12B) based on the event vernier pre-fetch load enable "EVR\_PREF\_LD[1:0].

The process of Figure 28B shows an operation for 25 inserting an extra clock cycle due to a carry detected by the carry-sum state machine 71 in Figure 14. The output "ZERO\_CY\_FLG" from the event count state machine 41 in Figure 7 is sent to the carry-sum state machine 71 in Figure 14 to request the event clock count. The carry-sum state machine 30 71 produces an extra cycle enable "EXTRA\_CY\_EN" which is sent to the scale counter logic 93 in Figure 16 where the extra cycle is added at the AND logic.

The process in Figure 28B also shows the window strobe generation. The window strobe logic 38 (Figure 22) generates 35 a window strobe output when two event vernier data (vernier

delay and event type) match with each other. The window strobe WSTB is one form of vernier data enable and is generated by the same timing as that of the vernier data enable "VER\_ENBL\_nP" (event enable) in Figure 28B by the 5 circuit configuration of Figure 18.

Figures 29A-29B, 30A-30B and 31A-31B show examples of how the event count and event vernier pipeline operates when a scale factor is "2". These diagrams are based on the timing shown in Figures 27A-27B and 28A and 28B, 10 respectively. The scaled timing shows the effect of wait states during each clock cycle. Namely, the event count scaling logic of Figure 16 inserts wait states into the event count state machine 41 equivalent to the scaling factor. Since the scale factor is "2", each event clock cycle uses 15 two master clock cycles. Thus, in Figures 29A, 30A and 31A, the event count data, for example, is loaded in the event counter 42 at the rate of event clock having a clock cycle which is two times of the master clock. The period signals PERIOD\_T in Figures 29B, 30B and 31B also show the same 20 repetition rate as that of the event clock.

The example of Figure 31A-31B also shows the effect of scaling on the vernier data enable "VER\_ENBL\_nP" (event enable) and window strobe WSTB. These signals depend upon the scaled values generated for the vernier delay data. 25 Thus, these signals occur in either of two master clock cycles. As noted above, the window strobe WSTB is generated by the same timing as that of the vernier data enable "VER\_ENBL\_nP" (event enable).

As has been described above, according to the present 30 invention, the event processing for a high speed event based test system can be effectively performed to produce the drive events and strobe events. The event data are compressed by dividing into two or more small words or segments and processed through two or more pipelines in a parallel 35 fashion. The decompression, summing and scaling processes

are conducted through the pipeline structure of the present invention. The event pipeline and summing logic also includes the window strobe logic for interpreting the event data and generating the window strobe. As a result, the 5 event pipeline and summation logic of the present invention achieves the high speed event processing and high operational stability in the event based test system.

Although only a preferred embodiment is specifically illustrated and described herein, it will be appreciated that 10 many modifications and variations of the present invention are possible in light of the above teachings and within the purview of the appended claims without departing the spirit and intended scope of the invention.